SOLID METAL BLOCK MOUNTING SUBSTRATES FOR SEMICONDUCTOR LIGHT EMITTING DEVICES, AND OXIDIZING METHODS FOR FABRICATING SAME

Field of the Invention

This invention relates to semiconductor light emitting devices and fabricating methods therefor, and more particularly to packaging and packaging methods for semiconductor light emitting devices.

Background of the Invention

Semiconductor light emitting devices, such as Light Emitting Diodes (LEDs) or laser diodes are widely used for many applications. As is well known to those having skill in the art, a semiconductor light emitting device includes one or more semiconductor layers that are configured to emit coherent and/or incoherent light upon energization thereof. It is also known that the semiconductor light emitting device generally is packaged to provide external electrical connections, heat sinking, lenses or waveguides, environmental protection and/or other functions.

For example, it is known to provide a two-piece package for a semiconductor light emitting device wherein the semiconductor light emitting device is mounted on a substrate that comprises alumina, aluminum nitride and/or other materials, which include electrical traces thereon, to provide external connections for the semiconductor light emitting device. A second substrate which may comprise silver plated copper, is mounted on the first substrate, for example using glue, surrounding the semiconductor light emitting device. A lens may be placed on the second substrate over the semiconductor light emitting device. Light emitting diodes with two-piece packages as described above are described in Application Serial No. 10/446,532 to Loh, entitled *Power Surface Mount Light Emitting Die Package*, filed May 27, 2003, assigned to the assignee of the present invention, the disclosure of which is hereby incorporated herein by reference in its entirety as if set forth fully herein.

Unfortunately, these substrates may be costly and, in some case, more costly than the semiconductor light emitting device themselves. Moreover, the fabrication

process may also be costly, time consuming and/or subject to failures due to the number of steps therein.

Summary of the Invention

Some embodiments of the present invention provide a mounting substrate for a semiconductor light emitting device that comprises a solid metal block including a cavity in a face thereof that is configured for mounting a semiconductor light emitting device therein. In other embodiments, an insulating coating is provided on a surface of the solid metal block. In still other embodiments, the insulating coating is in the cavity, and first and second spaced apart conductive traces are provided on the insulating coating in the cavity that are configured for connection to a semiconductor light emitting device.

In some embodiments, the first and second spaced apart conductive traces extend from the cavity to the first face around at least one side of the metal block and onto a second, opposite face of the metal block. In other embodiments, the solid metal block includes therein first and second through holes that extend from the first face to the second face of the metal block. A respective through hole includes a respective conductive via therein that extends from the first face to the second face. A respective one of the spaced apart conductive traces is electrically connected to a respective one of the conductive vias.

In some embodiments, the solid metal block is a solid aluminum block, and the insulating coating comprises aluminum oxide. The insulating coating may be formed by oxidizing the aluminum as will be described below. In these embodiments, the respective first and second through holes also include an insulating coating thereon that comprises aluminum oxide, so that the first and second conductive vias therein are insulated from the aluminum block.

Mounting substrates according to embodiments of the present invention may be combined with a semiconductor light emitting device that is mounted in the cavity and is connected to the first and second spaced apart conductive traces. A lens may be provided that extends across the cavity. In some embodiments, an encapsulant is provided between the semiconductor light emitting device and the lens. In other embodiments, a lens retainer may be provided on the substrate that is configured to hold the lens across the cavity.

Other embodiments of the present invention fabricate a mounting substrate for a semiconductor light emitting device by providing a solid aluminum block including a cavity in a face thereof that is configured for mounting a semiconductor light emitting device therein. The solid aluminum block is oxidized to form an aluminum oxide coating thereon. First and second spaced apart electrical traces are fabricated on the aluminum oxide coating in the cavity and are configured for connection of a semiconductor light emitting device thereto.

In some embodiments, the aluminum block also includes first and second through holes that extend therethrough. The first and second through holes are oxidized when oxidizing the second aluminum block, to form an aluminum oxide coating in the first and second through holes. First and second conductive vias are fabricated in the respective first and second through holes that are coated with aluminum oxide. In other embodiments, when fabricating the first and second spaced apart conductive traces, the traces are fabricated to extend from the cavity to the first face around at least one side of the metal block and onto a second face of the metal block that is opposite the first face.

In some embodiments, a semiconductor light emitting device is mounted in the cavity and connected to the first and second spaced apart conductive traces. In some embodiments, a lens is mounted across the cavity and, in some embodiments, an encapsulant is provided between the semiconductor light emitting device and the lens.

Brief Description of the Drawings

Figures 1A-1H are side cross-sectional views of mounting substrates for semiconductor light emitting devices according to various embodiments of the present invention.

Figure 2 is a flowchart of steps that may be performed to fabricate mounting substrates for semiconductor light emitting devices according to various embodiments of the present invention.

Figures 3A and 3B are top and bottom perspective views of a mounting substrate for semiconductor light emitting devices according to embodiments of the present invention.

Figure 4 is an exploded perspective view of a packaged semiconductor light emitting device according to embodiments of the present invention.

Figure 5 is an assembled perspective view of a packaged semiconductor light emitting device according to embodiments of the present invention.

Detailed Description

The present invention now will be described more fully hereinafter with reference to the accompanying drawings, in which embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. In the drawings, the size and relative sizes of layers and regions may be exaggerated for clarity. Like numbers refer to like elements throughout.

It will be understood that when an element such as a layer, region or substrate is referred to as being "on" another element, it can be directly on the other element or intervening elements may also be present. It will be understood that if part of an element, such as a surface of a conductive line, is referred to as "outer," it is closer to the outside of the device than other parts of the element. Furthermore, relative terms such as "beneath" may be used herein to describe a relationship of one layer or region to another layer or region relative to a substrate or base layer as illustrated in the figures. It will be understood that these terms are intended to encompass different orientations of the device in addition to the orientation depicted in the figures. Finally, the term "directly" means that there are no intervening elements.

Figures 1A-1H are side cross-sectional views of mounting substrates for semiconductor light emitting devices according to various embodiments of the present invention. Referring to Figure 1A, mounting substrates for semiconductor light emitting devices according to some embodiments of the invention include a solid metal block **100** including a cavity **110** in a first face **100a** thereof, that is configured for mounting a semiconductor light emitting device therein. In some embodiments, the solid metal block **100** comprises a solid aluminum block. The cavity **110** may be formed by machining, coining, etching and/or other conventional techniques. The size and shape of the cavity **110** may be configured to improve or optimize the amount and/or direction of light that is emitted by a semiconductor light emitting device that is mounted in the cavity **110**. For example, oblique sidewalls **110a** and or a semi-ellipsoidal cross-sectional profile may be provided. In some embodiments, the

metal block **100** may be a rectangular solid metal block of aluminum about 6mm x about 9mm, and about 2mm thick, and the cavity **110** may be about 1.2mm deep with a circular floor that is about 2.5mm in diameter, with sidewalls **110a** that are of any simple or complex shape to obtain desired radiation patterns. However, the block **100** may have other polygonal and/or ellipsoidal shapes.

Figure 1B illustrates mounting substrates according to other embodiments of the present invention. As shown in Figure 1B, an insulating coating is provided on the surface of the solid metal block **100**. The insulating coating **120** may be provided on the entire exposed surface of the solid metal block as shown in Figure 1B, or on only a portion of the exposed surface of the solid metal block. In some embodiments, as will be described below, the insulating coating **120** comprises a thin layer of aluminum oxide (Al_2O_3) that may be formed, for example, by anodic oxidation of the solid aluminum block **100**. In other embodiments, the coating **120** is sufficiently thick to provide an insulator, but is sufficiently thin to minimize the thermal conductive path therethrough.

Referring now to Figure 1C, first and second spaced apart conductive traces **130a, 130b** are provided on the insulating coating **120** in the cavity **110**. The first and second spaced apart conductive traces **130a, 130b** are configured for connection to a semiconductor light emitting device. As shown in Figure 1C, in some embodiments, the first and second spaced apart conductive traces **130a** and **130b** can extend from the cavity **110** onto the first face **100a** of the solid metal block **100**. When the insulating coating **120** is provided on only a portion of the solid metal block **100**, it may be provided between the first and second spaced apart traces **130a** and **130b** and the solid metal block **100**, to thereby insulate the first and second metal traces **130a** and **130b** from the solid metal block **100**.

Figure 1D illustrates other embodiments of the present invention wherein the first and second spaced apart conductive traces **130a', 130b'** extend from the cavity **110** to the first face **100a** around at least one side **100c** of the metal block and onto a second face **100b** of the metal block that is opposite the first face **100a**. Thus, backside contacts may be provided.

In some embodiments of the invention, the first and second spaced apart conductive traces **130a, 130b** and/or **130a', 130b'** comprise metal and, in some embodiments, a reflective metal such as silver. In other embodiments, as shown in Figure 1E, separate reflective layers **132a, 132b** may be provided on the spaced apart

conductive traces **130a'**, **130b'** in the cavity **110**. In these embodiments, the conductive traces **130a'**, **130b'** may comprise copper, and the reflective traces **132a**, **132b** may comprise silver.

In still other embodiments of the present invention, as illustrated in Figure 1F, backside contacts may be provided by providing first and second through holes **140a** and **140b**, which may be formed in the solid metal block **100** by machining, etching and/or other conventional techniques. Moreover, as shown in Figure 1F, the insulating coating **120** extends into the through holes **140a** and **140b**. First and second conductive vias **142a**, **142b** are provided in the first and second through holes **140a**, **140b**, and are insulated from the solid metal block **100** by the insulating coating **120** in through holes **140a**, **140b**.

In Figure 1F, the through holes **140a** and **140b**, and the conductive vias **142a** and **142b** extend from the cavity **110** to the second face **100b**. The through holes **140a**, **140b** may be orthogonal and/or oblique to the first and second faces **100a**, **100b**. First and second spaced apart conductive traces **130a'**, **130b'** may be provided in the cavity **110**, and electrically connected to the respective first and second conductive vias **142a**, **142b**. On the second face **100b**, third and fourth spaced apart conductive traces **130c**, **130d** also may be provided that are electrically connected to the respective first and second conductive vias **142a**, **142b**. A solder mask layer **144** may be provided in some embodiments to isolate the third and fourth conductive traces **130c**, **130d** on the second face **100b**, to facilitate circuit board assembly. Solder mask layers **144** are well known to those having skill in the art and need not be described further herein.

In embodiments of Figure 1F, the first and second through holes **140a**, **140b** and the first and second conductive vias **142a**, **142b** extended from the cavity **110** to the second face **100b**. In embodiments of Figure 1G, the first and second through holes **140a'**, **140b'** and the first and second conductive vias **142a'**, **142b'** extend from the first face **100a** outside the cavity **110** to the second face **100b**. The through holes **140a'**, **140b'** may be orthogonal and/or oblique to the first and second faces **100a**, **100b**. First and second spaced apart conductive traces **130a"**, **130b"** extend from the cavity **110** to the respective first and second conductive vias **142a'**, **142b'** on the first face **100a**. Third and fourth traces **130c'**, **130d'** are provided on the second face **100b** that electrically connect to the respective first and second conductive via **142a'**, **142b'**.

Figure 1H illustrates embodiments of the invention that were described in connection with Figure 1D, and which further include a semiconductor light emitting device **150** that is mounted in the cavity and that is connected to the first and second spaced apart electrical traces **130a'**, **130b'**. Moreover, Figure 1H illustrates that in other embodiments, a lens **170** extends across the cavity. In still other embodiments, an encapsulant **160** is provided between the semiconductor light emitting device **150** and the lens **170**. The encapsulant **160** may comprise clear epoxy and can enhance optical coupling from the semiconductor light emitting device **150** to the lens **170**. In still other embodiments, a lens retainer **180** is provided on the solid metal block **100**, to hold the lens **170** across the cavity **110**.

Embodiments of light emitting devices **150**, encapsulants **160** and lenses **170** that may be used in various embodiments of the present invention are described in U.S. Patent Application Serial No. __________, entitled *Transmissive Optical Elements Including Transparent Plastic Shell Having a Phosphor Dispersed Therein, and Methods of Fabricating Same*, to Negley et al. (Attorney Docket No. 5308-310), filed concurrently and assigned to the assignee of the present application, the disclosure of which is hereby incorporated by reference in its entirety as if set forth fully herein.

It will be understood by those having skill in the art that, although the embodiments of Figures 1F-1H have been illustrated as separate embodiments, various elements of Figures 1A-1H may be used together to provide various combinations and/or subcombinations of elements. Thus, for example, the reflective layer **132a**, **132b** may be used in any of the embodiments shown, and the semiconductor light emitting device **150**, lens **170**, encapsulant **160** and/or the lens retainer **180** may be used in any of the embodiments shown. Accordingly, the present invention should not be limited to the separate embodiments that are shown in Figures 1A-1H.

Figure 2 is a flowchart of steps that may be performed to fabricate semiconductor light emitting devices according to various embodiments of the present invention. Referring to Figure 2, as shown at Block **210**, a solid aluminum block, such as aluminum block **100** of Figures 1A-1H, is provided including a cavity, such as cavity **110**, in a face thereof, that is configured for mounting a semiconductor light emitting device therein. As was described above, the cavity may be provided by machining, coining, etching and/or other conventional techniques. Moreover, in other

embodiments, the solid aluminum block may also contain the first and second spaced apart through holes such as through holes **140a, 140b** and/or **140a', 140b'** that extend therethrough, and which may be fabricated by machining, etching and/or other conventional techniques.

Referring again to Figure 2, at Block **220**, the solid aluminum block is oxidized to form an aluminum oxide coating thereon. In some embodiments, the entire exposed surface of the solid aluminum block is oxidized. Moreover, when through holes are provided, the inner surfaces of the through holes also may be oxidized. In other embodiments, only portions of the aluminum block are oxidized, for example, by providing a masking layer on those portions which are desired not to be oxidized. Oxidization of aluminum is well known to those having skill in the art and may be performed, for example, using an anodic oxidation processes and/or other oxidation processes, to provide a thin layer of Al_2O_3 on the aluminum.

Still referring to Figure 2, at Block **230**, first and second spaced apart conductive traces, such as traces **130a, 130b** and/or **130a', 130b'**, are fabricated in the cavity on the first face, on the sides and/or on the second face, depending on the configuration, as was described above. Moreover, in some embodiments, conductive vias, such as vias **142a, 142b** and/or **142a', 142b'** may be fabricated in through holes. The conductive vias may be fabricated prior to, concurrent with and/or after the conductive traces. The fabrication of conductive traces on an aluminum core that is oxidized with aluminum oxide is well known to provide circuit board-like structures with an aluminum core, and accordingly need not be described in detail herein.

Finally, at Block **240**, other operations are performed to mount the semiconductor device, lens, encapsulant and/or retainer on the substrate.

Figures 3A and 3B are top and bottom perspective views, respectively, of mounting substrates according to embodiments of the present invention, which may correspond to the cross-sectional view of Figure 1D. Figures 3A and 3B illustrate the solid metal block **100**, the first and second spaced apart conductive traces **130a'**, **130b'** that wrap around the solid metal block, and the semiconductor light emitting device **150** mounted in the cavity **110**. The insulating coating **120** may be transparent and is not shown. A second insulating layer and/or solder mask may be provided on the first and/or second spaced apart conductive traces in these and/or any other embodiments.

Figure 4 illustrates an exploded perspective view of other embodiments of the present invention, which may correspond to Figure 1H. As shown in Figure 4, the solid metal block **100** includes a cavity **110** therein, and a plurality of spaced apart electrical traces thereon. In Figure 4, the first electrical trace **130a** is shown. However, rather than a single second electrical trace, a plurality of second electrical traces **330a'**, **330b'** and **330c'** may be provided to connect to a plurality of semiconductor light emitting devices **150'** that may be mounted in the cavity **110** to provide, for example, red, green and blue semiconductor light emitting devices for a white light source. The encapsulant **160** and lens retainer **180** are shown. Other configurations of lens retainers **180** can provide a ridge and/or other conventional mounting means for mounting a lens **170** on the solid metal block **100**. It also will be understood that an epoxy or other glue may be used in a lens retainer **180**. The lens retainer **180** may also provide additional top heat sinking capabilities in some embodiments of the present invention. Figure 5 illustrates the assembled package of Figure 4.

Accordingly, some embodiments of the present invention use a solid block of aluminum as a mounting substrate for a semiconductor light emitting device. Aluminum has sufficient thermal conductivity to be used as an effective heat sink. Additionally, the cost of the material and the cost to fabricate can be low. Moreover, the ability to grow high quality insulating oxides allows the desired electrical traces to be formed without a severe impact on the thermal resistance, since the thickness of the anodic oxidation can be precisely controlled. This insulating layer also can be selectively patterned, which can allow the addition of another plated metal to the substrate, such as plating silver on the cavity sidewalls only, for increased optical performance.

The ability to form an optical cavity in the substrate, rather than a separate reflector cup, can reduce the assembly costs, since the total number of elements for the package can be reduced. Additionally, the fact that the reflector (cavity) position is fixed with respect to the substrate can also reduce the assembly complexity. Embodiments of the invention may be particularly useful for high power semiconductor light emitting devices such as high power LEDs and/or laser diodes.

In the drawings and specification, there have been disclosed embodiments of the invention and, although specific terms are employed, they are used in a generic

and descriptive sense only and not for purposes of limitation, the scope of the invention being set forth in the following claims.